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Saliency and context play a role in infants' texture segmentation

Ruxandra Sireteanu [a,b,c,*], Irmgard Encke [b], Iris Bachert [b]

[a] Department of Biological Psychology, Institute of Psychology, Johann-Wolfgang-Goethe-University, 60054 Frankfurt/Main, Germany
[b] Department of Neurophysiology, Max-Planck-Institute for Brain Research, Deutschordenstr. 46, 60528 Frankfurt/Main, Germany
[c] Department of Biomedical Engineering, College of Engineering, Boston University, Boston, MA 02215, USA

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Abstract

We investigated whether young infants orient reliably towards more salient vs. less salient objects in a visual scene. Subjects were tested with stimuli presented on textured fields, one side showing a target stimulus (a 'more salient' or 'less salient' texture patch) and the other a background stimulus. Infants typically preferred the more salient, but not the less salient target. Their behaviour depended on the configuration of the background stimulus. In contrast, 3–4 year-old children always showed a preference for the target stimulus, regardless of the configuration of the background. We conclude that both saliency of a target stimulus and its context play a role in early texture segmentation.

Keywords: Infants; Texture segmentation; Saliency; Context

1. Introduction

In everyday life we extract figures without effort from a cluttered visual scene. This ability of the human brain, called *segmentation*, may be based on the coherence of the features which define a given object or by the contrast of their features with those of surrounding objects. Natural objects are usually defined by both, coherence of their features and contrast with the surrounding objects.

One aspect of visual segmentation is the *segmentation of textures* (cf. Beck, 1966, 1982; Bergen & Julesz, 1983; Julesz, 1981, 1984). Textures consist of arrays of micropatterns containing a group of items differing from the items of the background by a single feature. Sharp discontinuities between the different regions of the visual texture can often be perceived, while sometimes such discontinuities require careful scrutiny in order to be identified. The segmentation type depends on the kinds of elements within the target region and the relationship between these elements. If the group of discrepant elements can be detected immediately, its extraction is termed 'preattentive'. Elements supporting preattentive segmentation are known as *textons* (Bergen & Julesz, 1983; Julesz, 1981, 1984; but see Nothdurft, 1990, 1991, 1992).

In a related experimental paradigm, called *visual search*, a single odd item has to be located within an array of distracting elements. If the time needed to locate the discrepant element is independent of the number of distracting elements, the search is said to be *parallel*. The target item is said to *pop out* from the background of distracting items. If the search time increases with the numbers of distractors, the search is deemed to be *serial*, and is assumed to proceed by an element-by-element scrutiny of the experimental array. Elements for which the search is parallel, called *features*, are considered to form the elementary building blocks of visual perception

* Corresponding author. Address: Max-Planck-Institute for Brain Research, Department of Neurophysiology, Deutschordenstr. 46, 60528 Frankfurt/M., Germany. Tel.: +49 69 96769 277; fax: +49 69 96769 742.
E-mail address: sireteanu@mpih-frankfurt.mpg.de (R. Sireteanu).

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(Treisman & Gelade, 1980; Treisman & Gormican, 1988; Treisman & Souther, 1985). The features identified by a visual search process are not identical with the textons extracted by texture segmentation (Wolfe, 1992).

Effortless visual search and preattentive texture segmentation are considered to proceed in parallel across the visual field, as opposed to a serial, element-by-element scrutiny, thought to involve sequential shifts of attention (for a discussion of the limitations of this dichotomy and of the distinctions between visual search and texture segmentation, see Leonards, Rettenbach, & Sireteanu, 1998; Wolfe, 1992).

In this study, we investigated the segmentation of textures by infants and children. Previous findings made us suspect that infants' early segmentation abilities, reflected by their visual preferences, might be qualitatively different from those of adult observers.

In 1975, Salapatek reviewed a series of experiments conducted in his laboratory, which investigated the development of preferences for visual stimuli presented as matrices containing either a single discrepant element or groups of discrepant elements. Monitoring the side of first fixation in a 30-s presentation period, he found that 2-month-old infants show visual preferences fundamentally different from those of adults. Infants did not show a preference for discrepant objects; this preference emerged somewhere between 2 months and 3 years of age. In some instances, 2-month-old infants even showed an intriguing *negative* preference, i.e. they oriented *away* from a discrepant stimulus (for instance, a group of parallel line segments embedded in a matrix of squares). The infants preferred the side of the display containing *more squares*, regardless of whether the pattern elements were darker or brighter than the surround. Salapatek (1975) concluded that infants' visual orienting behaviour might be governed by factors like contour density, local brightness, or shape, instead of the preference for discrepant targets, shown by adult observers.

Infants' segmentation of oriented textures was later investigated independently and concomitantly by Atkinson and Braddick (1992) and Sireteanu and Rieth (1992).

Atkinson and Braddick presented infants with textures of obliquely oriented lines containing either a discrepant group of orthogonally oriented lines or a group with an increased density of lines, thus containing a luminance difference between target and surround. They found that segmentation of oriented textures emerges between 10 and 16 weeks of age and is slower to develop than segmentation based on luminance differences.

Sireteanu and Rieth (1992) used textures containing either obliquely oriented line segments or dark blobs on a bright background. The target could be a texture of an orthogonal orientation or a group of larger blobs. They found that infants started to segment oriented textures toward the end of the first year of life. This ability does not become adult-like before school age, while segmentation of textures based on differences in blob size is accomplished by infants as young as 2 months of age. Thus, although the two studies agree that the segmentation of textures containing luminance differences occurs very early in life, and the segmentation of oriented textures requires a more protracted developmental period, they differed on the age of onset of the latter function. This difference might be due to differences in the stimulus parameters used in the two studies (Rieth & Sireteanu, 1994a, 1994b).

The neural substrate of the late development of segmentation of oriented textures was proposed to reside in the long-range, tangential connections in the primary visual cortex (Atkinson & Braddick, 1992; Sireteanu, 2000, 2001; Sireteanu & Rieth, 1992), which are known to emerge after birth and take several years to reach maturity (Burkhalter, Bernardo, & Charles, 1993). This hypothesis was reinforced by Kovacs (2000), who found that the binding of individual oriented Gabor patches into a coherent figure, as well as the perception of some well-known visual illusions known to require tangential connections (e.g., the Ebbinghaus illusion) take several years to reach maturity (see also Kovacs, Kozma, Feher, & Benedek, 1999).

Two further aspects govern visual preferences in adult observers, namely *saliency* and *context*. Previous studies have shown that items displaying more, respectively less of a certain visual attribute (local luminance, size, colour saturation) than the surrounding items are processed differently in a visual search task (Treisman & Gormican, 1988; Treisman & Souther, 1985). Braun (1994) investigated the role of attention on the processing of target stimuli displaying more or less of a given quality than the surrounding items (he called these targets 'most salient', respectively 'least salient'). He found that withdrawal of attention selectively compromises perfomance for the less salient targets, while leaving performance for the more salient objects relatively unaffected. These results suggest that processing of perceptual objects of differing saliency might represent functionally different tasks, with probably different functional mechanisms underlying their execution.

Studies on visual preferences in early infancy have capitalized on the innate tendency of preverbal subjects to orient towards the *most salient* object in a visual scene: the only patterned patch on an otherwise uniformly gray background, the larger, colored, moving, or stereoscopically conspicuous object over a gray, stationary, or flat surround. But in real life, visual objects might be defined by being *less salient* (smaller, grayer, paler, quieter, flatter etc.) than their surrounding objects. While a large body of evidence is accumulating about infants' preferences for visual objects more salient than their surroundings, relatively little is known about the preferences of young infants for visual objects less salient than their surround.

In the present study, we attempt to fill this gap, by trying to delineate the developmental paths of segmentation of a 'less salient', as opposed to a 'more salient' texture-defined object. We define a *salient* object as a visual object differing from its surround by a physical increment in one stimulus dimension. More specifically, we investigated infants' preferences for objects defined by a *larger* ('more salient') or a *smaller* ('less salient') size of their constituent elements.

In the first part of the study, we investigated the role of *saliency* in early visual preferences. In Experiment 1, we investigated infants' looking behaviour toward a 'more salient' or a 'less salient' texture-defined target in comparison with a uniform background, using a forced-choice preferential-looking procedure, with stimuli presented on two separate texture fields. In Experiment 1A, we used the same stimuli, but replaced the forced-choice preferential-looking procedure by a method of first fixation and a limited observation time. In Experiment 2, we tested infants and children with texture stimuli presented on a single, continuous test field, using cardboard cards.

In the second part of the study, we asked whether the *context* in which the texture is seen can influence the infant's behaviour. In Experiment 3, the 'more salient' and the 'less salient' target textures were paired with the reversed backgrounds ('more salient' stimulus paired with a uniform field containing large blobs; 'less salient' stimulus paired with a uniform field containing small blobs). In Experiment 4, the 'more salient' and 'less salient' target stimuli were paired with background stimuli containing the same number of large and small blobs as the target stimuli, but randomly distributed among the other blobs. Finally, in Experiment 5, the 'more salient' and the 'less salient' target stimuli were paired with the reversed backgrounds of Experiment 4.

The results showed that both the saliency of a texture target and its contextual embedding are important in early texture segmentation. Part of the results of these experiments were presented in preliminary form (Sireteanu, 2000; Sireteanu, Encke, & Bachert, 2003).

2. General methods

We used a combination of a forced-choice preferential-looking procedure (FPL; Dobson & Teller, 1978; Gwiazda, Brill, Mohindra, & Held, 1978; Teller, 1997; Teller, Morse, Borton, & Regal, 1974) with stimuli presented on slides and projected on two separate test fields (for details, see Sireteanu, 2000; Sireteanu et al., 2003; Sireteanu, Fronius, & Constantinescu, 1994; Sireteanu, Kellerer, & Boergen, 1984; Sireteanu & Rieth, 1992) and a preferential-looking procedure with stimuli presented on cards (McDonald et al., 1996; see also Sireteanu, 2000; Sireteanu et al., 2003; Sireteanu & Rieth, 1992).

2.1. Subjects

The subjects were infants between 1 and 12 months of age ($n = 96$), children between 3 and 4 years of age ($n = 36$) and adult observers ($n = 32$). Only full-term subjects with no developmental abnormalities were included in the study. Prior to the experiments, the subjects underwent a full orthoptic examination, consisting of a visual acuity test using the Teller Acuity Cards, a cover test and eye motility test for assessing the binocular status, the Lang Test for measuring stereopsis, and a refraction test using the Cambridge VPR1 Paediatric Videorefractor and the plusoptiX CR03. These tests were performed by a trained orthoptist (I.B.). Subjects with visual disorders were referred to an ophthalmologist and not included in the study.

The subjects were recruited by announcements in family health care centers and at local pediatricians' offices. With the exception of the informed adult observers, all participants were naïve to the purpose and the procedure of the study. Informed consent was obtained from the subjects or the parents after the procedure was explained fully. The experiments were conducted in accordance with the Declaration of Helsinki. The study was approved by the Ethical Committee of the Frankfurt University.

2.2. Experiments with slide stimuli (Experiments 1, 1A, 3, 4 and 5)

2.2.1. Stimuli

The subject was seated in front of a gray screen containing two circular apertures with a diameter of 15° each, centered at 20° from the midline. The stimuli were textured fields presented on slides, projected from behind on the two apertures. One stimulus side contained a figure embedded in a background; the other showed the background alone (for details, see Sireteanu, 2000; Sireteanu et al., 2003; Sireteanu et al., 1994; Sireteanu et al., 1984).

'*More salient*' *stimulus*: The target stimulus contained a group of 4×4 neighboring large blobs (0.8° diameter) standing out from the background of smaller blobs (0.3° diameter). The blobs were black, randomly arranged on a white background (see also Rieth & Sireteanu, 1994a, 1994b; Sireteanu & Rieth, 1992).

'*Less salient*' *stimulus:* The target stimulus consisted of a group of 4×4 small blobs (0.3° diameter), embedded in a background of large blobs (0.8° diameter). The spacings of the individual blobs were identical to those of the 'most salient' stimulus.

2.2.2. Apparatus

Testing took place in a darkened room. The subject was placed at a distance of 57 cm in front of a large wooden screen containing the stimuli. Mean luminance of the stimuli was 70 cd/m^2. Four red blinking lamps, two of which could be lit at a time, were arranged around a small central peep-hole (2° in diameter). The apertures were placed such that they approximated the subjects' eye level. Four small red blinking lamps were arranged around the peep-hole. Two of them (either vertical or horizontal) served as a centering stimulus in between the trials. A videocamera focusing on the subject's face was positioned behind the peephole. The image of the subject's face could be seen by an observer via the videocamera on a monitor screen (Rieth & Sireteanu, 1994a, 1994b; Sireteanu, 2000; Sireteanu et al., 2003; Sireteanu et al., 1994; Sireteanu & Rieth, 1992).

2.2.3. Procedure

Throughout the study, testing was binocular. The subject sat on a parent's lap or by her/himself in front of the screen containing the two apertures. The parent had been instructed not to point or interact with the child in any way that would influence her/his behaviour. Previous observations from our laboratory (Sireteanu & Fronius, unpublished) and from other groups (Atkinson, personal communication) showed that obstruction of the stimulus from the subjects' view yielded results similar to those obtained when letting the parent to freely view the experimental display, while rendering both infant and parent more uncomfortable with the experimental situation. We therefore did not obstruct the parents' view of the stimuli.

Each session consisted of 20 trials for infants and 40 trials for older children and adults. To judge whether the subjects stayed attentive, four additional stimuli (drawings of faces, toys, animals) were included randomly in each 40-trial session. An adult observer, naïve to which configuration the child was seeing in each trial, looked at the subject's face on the monitor screen. The observer's task was to decide on the basis of the subject's looking behavior (side and duration of the first fixation, longest fixation, interested scanning, etc.) which side the target stimulus might have been presented on. There was no time limit for the observer's decision. The stimuli were presented in a pseudo-randomized order (not more than two identical stimuli in a row). All sessions were judged in a 'live' situation and also recorded on videotape.

The method used for children and for naïve adults was identical to that used for the infant subjects. The results of the adult observers were scored by the same observer (I.E.) as the infants and children tested in the same experiments. Informed adults were asked to 'behave spontaneously', i.e. not to refrain from scanning both sides of the display, if they felt the urge to do so. Judgements were always based on observation of the subjects' looking behaviour. Pointing or verbal responses were ignored.

At the end of the session, the percentages of correct responses were calculated. No preference corresponds to 50% correct (chance level). To determine whether orienting responses were statistically reliable, we calculated whether differences from 50% were statistically significant, using a one-sided Student t-test. A score of $p < 0.05$ was deemed statistically significant, a score of $p < 0.01$ statistically highly significant.

2.3. Experiments with card stimuli (Experiment 2)

2.3.1. Stimuli

The stimuli of Experiment 2 were textures consisting either of small blobs with a target stimulus made of 4×4 large blobs ('*more salient*' stimulus), or of large blobs containing a target stimulus made of 4×4 small blobs ('*less salient*' stimulus) on one side. The blobs were black (mean luminance 12 cd/m^2) on a white background (mean luminance 106 cd/m^2). The stimuli were presented on cardboard cards. To replicate the conditions of the study of Sireteanu and Rieth (1992), the blobs were 1.6° (large blobs) and 0.6° (small blobs) in diameter.

2.3.2. Apparatus and procedure

We used a modified preferential-looking procedure, adapted from the Teller Acuity Card procedure (McDonald et al., 1996). The subjects were tested in a well lit experimental room. The child was held by a parent in front of a gray three-sided wooden construction resembling a puppet theatre, containing a rectangular opening in which the card was presented, hand-held by the observer. The child was held at a distance of 57 cm from the card. The cards were 25×56 cm of size, replicating the size of the Teller Acuity Cards (McDonald et al., 1996).

The observer, masked to the side and identity of the stimulus, looked at the child's face through a small peep-hole at the center of the card. Based on the subject's reaction and after having turned the card several times (typically three times), she made a judgment on the subject's preferred side of the card. A second experimenter recorded in the protocol whether the target was on the subject's preferred side or not. In between the presentations, the observer made verbal contact to the subject. This social contact, meant to maintain the infants' attention, was found to be at least as compelling for the infants as the four drawing stimuli in Experiment 1. All observations of this Experiment were done by the same observer as in Experiments 1 and 1A (I.E).

3. Experiment 1: The role of saliency in early texture segmentation

3.1. Introduction

In this Experiment, we investigated whether infants and children, known to have a preference for the 'more salient' texture-defined target stimulus (Sireteanu & Rieth, 1992), also orient reliably towards the 'less salient' stimulus. We use the term 'saliency' as defined in the Introduction, 'more salient' meaning a target stimulus defined by a local physical increment in one dimension (here: larger size of its items) against its surround, and 'less salient' meaning a target stimulus defined by a physical decrement in the same dimension (here: smaller size) relative to its surround. Thus, the 'more salient' target contained the most prominent and the 'less salient' target the least prominent local cues, while boundary contrast was identical in the two target stimuli.

3.2. Methods

3.2.1. Apparatus and procedure

The stimuli were presented on two separate textured fields. The 'more salient' stimulus was paired with a background stimulus consisting of small blobs. The 'less salient' stimulus was presented together with a stimulus consisting of large blobs (see Fig. 1).

3.2.2. Subjects

The infant data were based on four groups of infants, each consisting of 12 subjects. Group I (1–3 month-olds) included infants aged between 1 month 12 days and 3 months 7 days (mean age: 2 months 1 day). In group II (4–6 month-olds), the infants were aged between 3 months 27 days and 5 months 22 days (mean age: 4 months 22 days). Infants in group III (7–9 month-olds) were aged between 7 months 1 day and 9 months 4 days (mean age: 7 months 28 days). Group IV (10–12 month-olds), consisted of infants between the ages of 9 months 25 days and 11 months 22 days (mean age 10 months 23 days). Care was taken to include an approximately equal number of girls and boys in each age group.

In addition, we examined twelve 3–4 year-old children, aged between 3 years 0 months and 4 years 3 months (mean age 3 years and 9 months), 16 informed adult observers, aged between 21 and 49 years (mean age 30 years) and 16 naïve adult observers, aged between 23 and 42 years (mean age 30 years).

Data from 21 subjects were eliminated because of gaze preference (6 cases), fussiness (9 cases), technical problems (2 cases), or eye disorders (4 cases).

3.3. Results and discussion

All adult subjects showed high, statistically highly significant ($p < 0.01$) preferences for the target stimulus in both tasks. Informed adults' preferences for the 'less salient' stimulus were slightly lower (86%) than those for the 'more salient' stimulus (96%). We interpret the fact that the preference of the informed adults was not 100% (in spite of their knowing the task) as reflecting the subjects' scanning back and forth between the two texture fields. This urge to inspect the field not containing a target was obviously higher if this field consisted of large blobs. For naïve adult observers, performances in both tasks were lower than for the instructed subjects

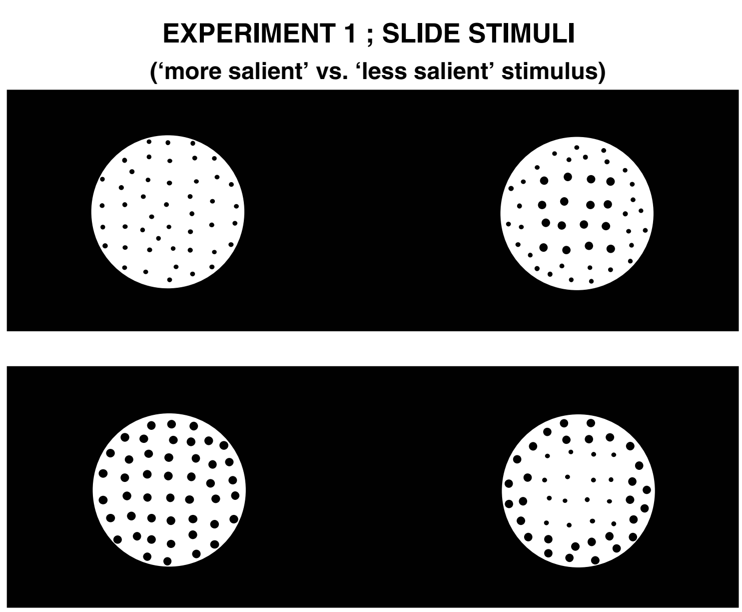

Fig. 1. Stimuli used in Experiment 1 (slide stimuli). Upper panel: 'more salient' stimulus. Lower panel: 'less salient' stimulus.

(76% for the 'more salient' and 63% for the 'less salient' stimulus; see Table 1 and Fig. 2).

Infants aged 1–3, 4–6, 7–9, and 10–12 months showed high, statistically highly significant ($p < 0.01$) preferences for the 'more salient' stimulus (preference scores ranged between 64% and 75%). None of the infants showed a significant preference for the 'less salient' stimulus. Infants in all age groups looked at the side of the display containing the 'less salient' stimulus at chance level (52–55%; $p > 0.10$; see Table 1 and Fig. 3).

Three-to-four year-old children preferred both the 'less salient' and the 'more salient' target stimulus highly significantly (74% and 78%, respectively; $p < 0.01$; see Table 1 and continuous lines in the right panel in Fig. 4). Interestingly, children showed a higher preference for the 'less salient' stimulus than the naïve adult observers.

The finding that all infants showed statistically highly significant preferences for the 'more salient' stimulus confirms the results of Sireteanu and Rieth (1992). However, none of the infants show a preference for the 'less salient' stimulus. This preference emerges somewhere between 1 year and 3–4 years of age.

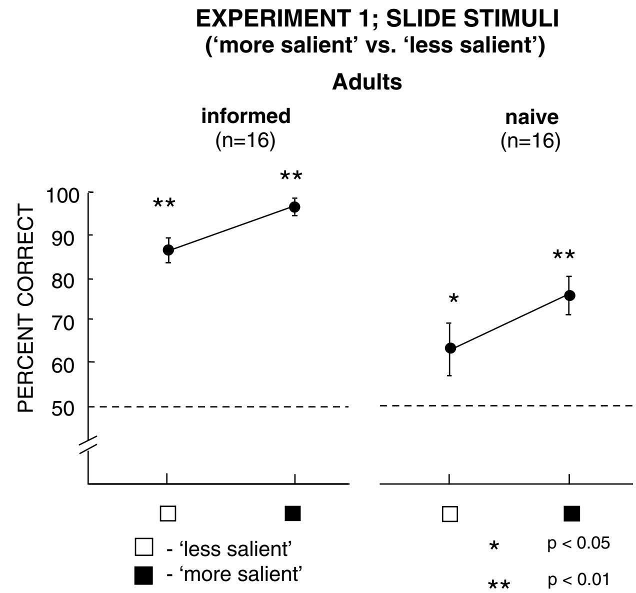

Fig. 2. Results of Experiment 1. Means and standard errors of percent correct responses for the 'more salient' and the 'less salient' stimulus in informed (left panel) and naïve adult observers (right panel; 16 subjects/group).

4. Experiment 1A: The role of the experimental procedure

4.1. Introduction

The results of Experiment 1 were obtained using a forced-choice preferential-looking procedure. To control for the possibility that the infants might have shown a brief initial response to the 'less salient' stimulus, which might have been overlooked by the observer, we reanalyzed the tapes obtained in Experiment 1, by using a first-fixation procedure, similar to the one used by Salapatek (1975). Previous experiments from our laboratory had demonstrated that the forced-choice decision of a naïve observer does not differ between live and videorecorded material of the same experimental session, even when scored by different observers (Sireteanu, Neu, Fronius, & Constantinescu, 1998).

4.2. Methods

The data from all 1–3 month-old infants and 3–4 year-old children included in Experiment 1 were reanalysed from the videotapes recorded during the experi-

Table 1
Summary of the results of Experiment 1

Age groups	n	Means (%)	Stand. error (%)	t	d.f.	p
More salient stimuli						
1–3 months	12	75.17	3.29	7.66	11	0.000**
4–6 months	12	64.42	5.09	2.83	11	0.008**
7–9 months	12	64.58	2.95	4.94	11	0.000**
10–12 months	12	64.25	2.89	4.93	11	0.000**
3–4 years	12	78.33	2.13	13.33	11	0.000**
Adults (naive)	16	75.69	4.47	5.75	15	0.000**
Adults (informed)	16	96.38	1.17	39.69	15	0.000**
Less salient stimuli						
1–3 months	12	52.92	4.17	0.70	11	0.250
4–6 months	12	54.33	5.11	0.85	11	0.208
7–9 months	12	54.75	3.59	1.32	11	0.106
10–12 months	12	52.08	3.52	0.59	11	0.283
3–4 years	12	73.50	2.50	9.40	11	0.000**
Adults (naive)	16	63.06	6.04	2.16	15	0.024*
Adults (informed)	16	86.37	2.77	13.13	15	0.000**

*$p < 0.05$, **$p < 0.01$.

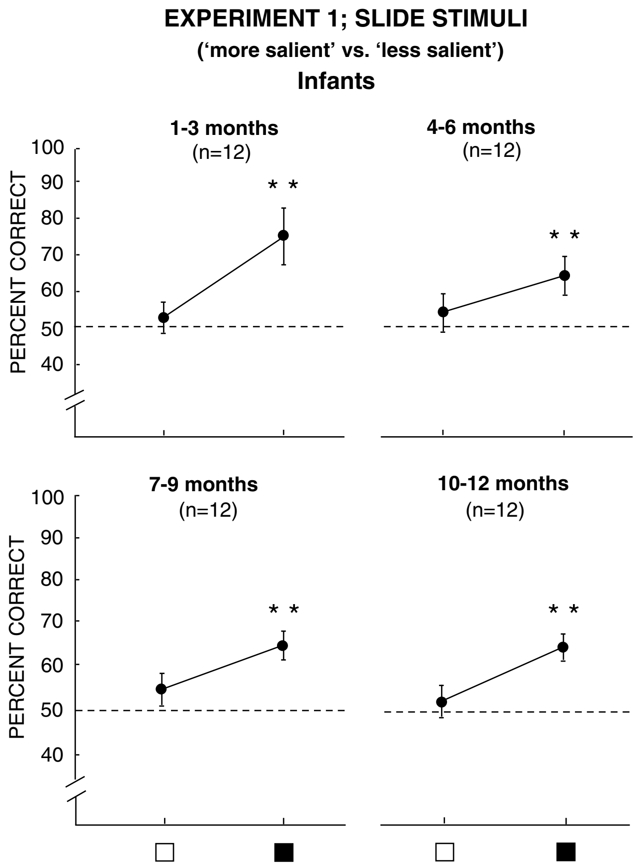

Fig. 3. Results of Experiment 1. Means and standard errors of the percent correct responses for the 'more salient' and the 'less salient' stimulus in infants under one year of age (four age groups; 12 infants/group).

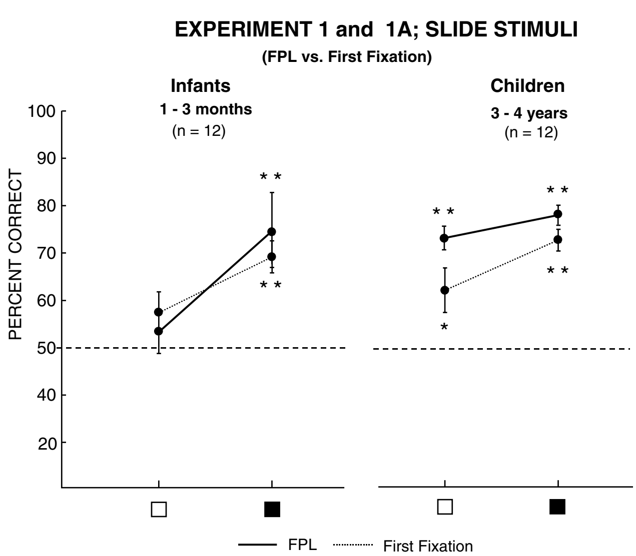

Fig. 4. Results of Experiments 1 and 1A. Means and standard errors of the percent correct responses in 1–3 months old infants and 3–4 year-old children (12 subjects/group). Continuous lines: Results obtained with the forced-choice preferential looking procedure. Dotted lines: Results obtained from videotaped material of the same subjects, using a first-fixation criterion.

mental sessions, this time using a first fixation criterion. The task of the observer was to decide, based on the videotaped material, to which side of the display the first fixation of the subject was directed. A 30-s limitation was imposed on the observation time.

4.3. Results and discussion

The 'first fixation' method yielded results qualitatively similar to those of the forced-choice preferential-looking procedure (see dotted lines in Fig. 4). For the 1–3 month-old infants, preference for the 'more salient' stimulus was statistically highly significant (70%, $p < 0.01$), while for the 'less salient' stimulus, it was at chance level (57%, $p > 0.10$). For the 3–4 year-old children, both the 'more salient' and the 'less salient' target stimuli yielded statistically significant responses ('more salient': 73%, $p < 0.01$; 'less salient': 63%, $p < 0.05$).

The preferences of the 3–4 year-old children were consistently lower when using the first fixation procedure than with the forced-choice preferential-looking method. This result probably reflects the possibility that the first fixation procedure yields preferences which are based on a peripheral location of the stimuli, while the forced-choice preferential-looking procedure approximates a foveal positioning of the stimuli (see also Sireteanu et al., 1984, 1994). Such a difference is not to be expected in 1–3 month-old infants, in which the foveal specialization is still undeveloped (Youdelis & Hendrickson, 1986).

Thus, it appears that the absence of a preference for the 'less salient' stimulus in 1–3 month-old infants is independent of the experimental procedure used.

5. Experiment 2: The role of the stimulus configuration

5.1. Introduction

To make sure that the results of Experiment 1 were not due to the presentation of the stimuli on two separate test fields, we performed an Experiment in which the stimuli were presented on a single, continuous test field.

5.2. Methods

5.2.1. Stimuli

The stimuli were presented on cardboard cards, 25 cm × 56 cm of size. The 'more salient' stimulus contained a group of 4×4 large blobs embedded in a background of small blobs. The 'less salient' stimulus contained a group of 4×4 small blobs embedded in a background of large blobs (see Fig. 5).

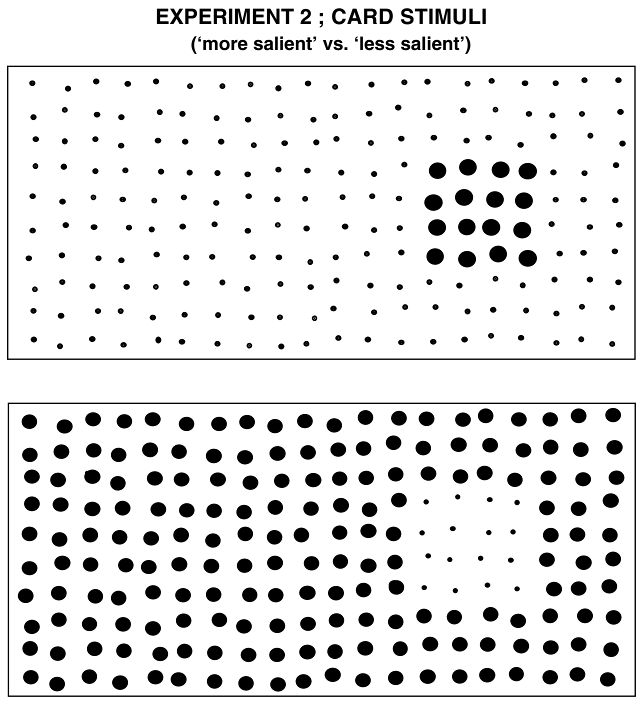

Fig. 5. Stimuli used in Experiment 2 (card stimuli). Upper panel: 'more salient' stimulus; lower panel: 'less salient' stimulus.

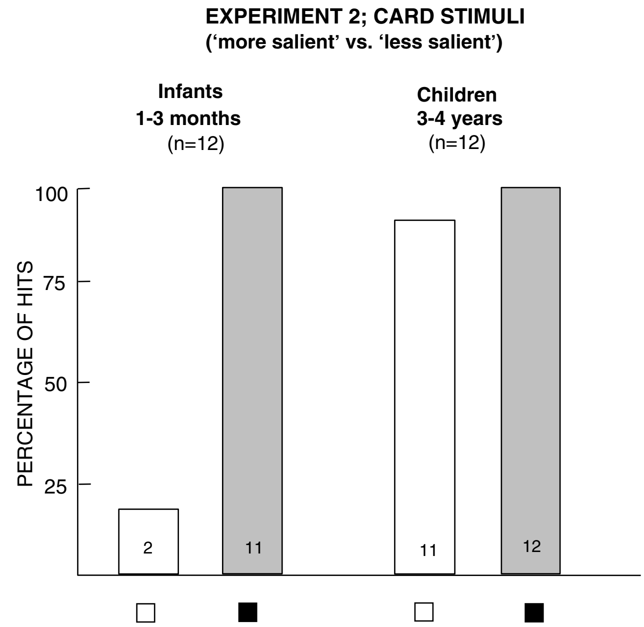

Fig. 6. Results of Experiment 2. Percentage correct responses obtained with 1–3 month-old infants (left panel) and 3–4 year-old children (right panel) for texture-defined 'more salient' (gray columns) and 'less salient' stimuli (white columns; 12 subjects/group). Figures indicate the actual number of infants yielding correct responses.

5.2.2. Subjects

We tested 12 infants 1–3 months of age, aged between 1 month 21 days and 3 months 15 days (mean age 2 months and 3 days) and 12 children 3–4 years of age, aged from 3 years and 0 months to 4 years and 4 months (mean age 3 years and 9 months). None of these subjects had taken part in Experiment 1.

5.3. Results and discussion

All subjects preferred the side of the card containing the 'more salient' stimulus (100%). Eleven out of the twelve 3–4 year-old children (92%), but only two out of the twelve 1–3 month-old infants (17%) oriented toward the side of the card containing the 'less salient' stimulus (see Fig. 6).

The results of this Experiment confirm the results of Experiments 1 and 1A and show that the asymmetry in the preferences for the 'more salient' and the 'less salient' texture-defined stimulus in young infants is not dependent on the configuration of the stimuli and the experimental procedure.

One might argue that the 'less salient' stimulus in Experiment 2 might be seen as a luminance decrement, i.e. a lighter square on a darker background, whereas the 'more salient' stimulus could be assimilated to a darker square on a lighter background. To control for the possibility that this asymmetry might have caused a differential preference in the young infants, in a related study, presented elsewhere (Sireteanu et al., 2003), we tested 2-month-old infants using card stimuli containing luminance differences, but no texture-defined targets. The infants were presented with gray cardboard cards, containing either a white or a black square on one side. Eleven out of 12 infants (92%) preferred the side of the card containing the black square and 9 out of 12 (75%) showed a preference for the white square. Both preferences are highly significant, but they do not differ significantly from each other. This result is in strong contrast with the pattern of preferences for the texture-defined 'more salient' vs. 'less salient' stimuli in Experiment 2, suggesting that the results of Experiments 1, 1A and 2 can be explained by processes of texture segmentation and not by differences in luminance between target and background.

5.4. Summary and comments

Taken together, the results of Experiments 1, 1A and 2 clearly show that young infants do not show a preference for a texture-defined visual object whose elements are less salient than the items of the surround. This finding is in line with the results of Salapatek (1975). However, we did not confirm Salapatek's finding that infants might have a *negative* preference for a less salient texture-defined target stimulus (in his case, a group of parallel line segments embedded in a matrix of squares). While our 3–4 year-old subjects showed a positive preference for both the 'more salient' and the 'less salient' target stimuli, our 1–3 month-old infants disregarded the target stimulus defined by a smaller size of its constituent items.

The reason cannot lie in the different procedures used in the two studies, since we replicated our results with the method of first fixation used in the Salapatek study. Note, however, that the stimuli used by the two studies were not entirely equivalent: the elements in Salapatek's target stimulus differed from those of the surround not only in brightness, but also in the amount and complexity of their contour. In our case, the items of the target (small blobs) differed from those of the background (large blobs) in size (and consequently in brightness), but not in shape. Thus, one of the reasons suggested by Salapatek—contour density—might have been responsible for the reverse preference seen in his study.

Another explanation might reside in the different attentional requirements of the stimuli: In our study, the infants' attention might have been attracted by both the individual large blobs (local luminance cue), as well as by the texture border between the large and small blobs (contour cue). For the 'more salient' stimulus, both cues are located on the same side of the display and thus might add, to command a clear preference for this side. For the 'less salient' stimulus, the two attentional attractors are located on opposite sides of the experimental array, and thus might create a conflicting situation. With increasing age, the attentional weight of the contour border might increase, and thus enable an overt orienting reaction toward the side of the display containing the discrepant patch. This tentative explanation might also accommodate the results of Salapatek: It could be that the relative dominance of the background squares over the single lines used in his experiments exceeded that of the larger over the smaller blobs used in our experiments (for an interpretation of Salapatek's matrix experiments, see Banks & Ginsburg, 1985). The following experiments were designed to investigate the possibility that the infants' preferences might be context-dependent (Dannemiller, 2000).

6. Experiment 3: The role of context in early texture segmentation (reversed background)

6.1. Introduction

In the previous Experiments, we found that infants under one year of age do not show a visual preference for a texture-defined target of small blobs embedded in a background of large blobs. The question arises whether this lack of preference for the target of small blobs is due to the fact that the infants do not perceive it as a target (it is not a visual object, able to elicit a "visual grasp reflex"), or whether this stimulus was not preferred because it was competing with a strongly attractive background stimulus (an array of large blobs). In order to determine whether the background stimulus might create a conflict in infants' looking ability, in Experiment 3 we used the target stimuli of Experiment 1, but paired with reversed background stimuli.

6.2. Methods

6.2.1. Stimuli

In a first configuration, the target stimulus consisted of small blobs with an embedded group of 4×4 large blobs ('more salient' target), while the background stimulus contained only large blobs. In the second stimulus configuration, the target stimulus was represented by 4×4 small blobs surrounded by large blobs ('less salient' target), while the background stimulus consisted only of small blobs (see Fig. 7).

6.2.2. Apparatus and procedure

We used the same apparatus and procedure as in Experiment 1.

6.2.3. Subjects

In this Experiment, we tested subjects in two groups (1–3 months and 3–4 years), each containing 12 subjects. The 1–3 month-olds ranged between 1 month and 13 days and 2 months and 26 days (mean age 2 months and 13 days), the 3–4 year-olds between 3 years 0 months and 4 years 1 month (mean age 3 years and 5 months).

6.3. Results and discussion

Three-to-four year-old subjects showed positive preferences for both stimuli, even if the preferences were definitely lower than in Experiment 1 (right panel in Fig. 8;

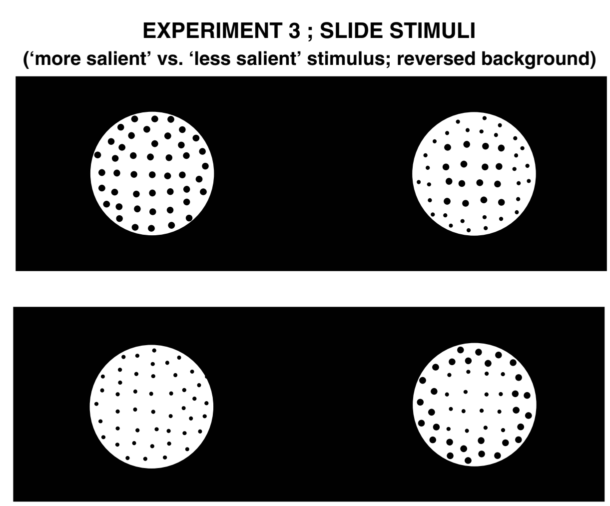

Fig. 7. Stimuli used in Experiment 3. Upper panel: 'more salient' stimulus with reversed background; lower panel: 'less salient' stimulus with reversed background.

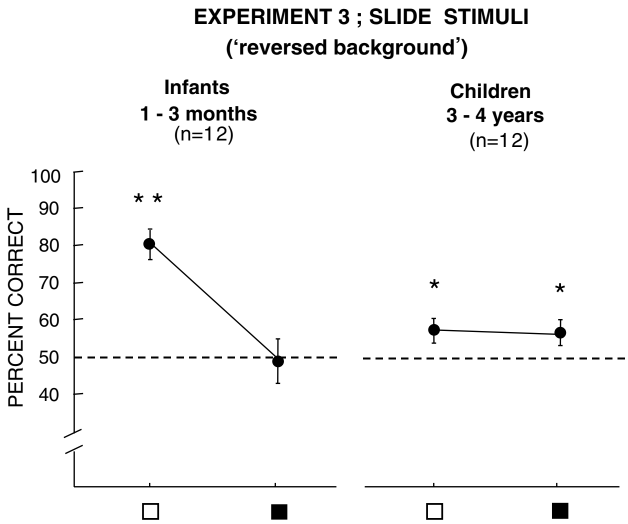

Fig. 8. Results of Experiment 3. Percent correct responses for the 'more salient' and the 'less salient' stimuli with reversed background in 1–3 month-old infants (left panel) and 3–4 year-old children (right panel; 12 subjects/group).

for a comparison, see right panel in Fig. 4). Preference for the 'less salient' stimulus was 58%; preference for the 'more salient' stimulus was 57%. Both preferences were statistically significant ($p < 0.05$). Infants 1–3 months of age showed a statistically highly significant preference for the 'less salient' stimulus (78%; $p < 0.01$), but they only looked at the 'more salient' stimulus at chance level (47%; see left panel in Fig. 8).

Thus, 1–3 month-old infants show an overwhelming preference for the 'less salient' target stimulus, if this stimulus is paired with a background stimulus consisting only of small blobs. Three-to-four year-old children prefer both target stimuli in this configuration.

There are two possible interpretations: First, it could be that the infants are able to segment both the 'more salient' and the 'less salient' stimulus, but in Experiment 1, the preference for the 'less salient' target stimulus might have been overshadowed by their preference for the single salient items on the other side of the display. Second, it could be that 2-month-old infants do not segment the textures, but simply prefer the side of the display containing large blobs. If large blobs are present in both stimuli, they might prefer neither side. The next two Experiments were designed to decide between these possibilities.

7. Experiment 4: Preferences for conflicting, balanced stimuli (distributed background)

7.1. Introduction

In Experiment 4, infants aged 1–3 months were presented with the 'more salient' or the 'less salient' target stimuli, each paired with a field containing the same amount of small and large blobs as the target stimuli, but randomly intermingled. Thus, the subjects were confronted with a figure stimulus and a background stimulus, both containing the same number of large and small blobs. We wondered whether the background stimulus—small and large blobs not representing a figure—might present a conflict with the figure stimulus.

7.2. Methods

7.2.1. Stimuli

The 'more salient' target stimulus was paired with a background stimulus in which 16 large blobs (the same number as in the target stimulus) were distributed randomly among small blobs (see Fig. 9, upper panel). The 'less salient' target stimulus was paired with a background stimulus in which 16 small blobs (again the same number as in the target stimulus) were distributed randomly between large blobs (see Fig. 9, lower panel).

7.2.2. Apparatus and procedure

We used the same apparatus and procedure as in Experiments 1 and 3.

7.2.3. Subjects

We tested 12 infants 1–3 months of age. The ages of the subjects in the first group ranged from 2 months 2 days to 3 months 16 days, with a mean age of 2 months and 25 days.

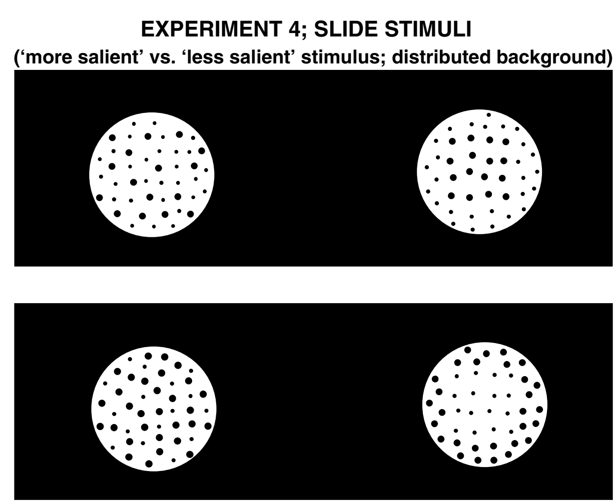

Fig. 9. Stimuli used in Experiment 4. Upper panel: 'more salient' stimulus, paired with a background stimulus containing the same number of large blobs, randomly interspersed amidst small blobs. Lower panel: 'less salient' stimulus, paired with a background containing the same number of small blobs, randomly interspersed amidst large blobs.

7.3. Results and discussion

Infants did not show a preference for any of the target stimuli. In fact, they looked at the 'more salient' stimulus with a "preference" of 48%; the 'less salient' stimulus evoked a preference of 52% (both $p > 0.1$; see left lower panel in Fig. 11). The infants showed a very different looking behavior in this Experiment than in the previous ones. The most apparent difference was that all infants compared both sides (the target stimulus and the field showing the same number of large and small blobs) much more actively and faster than in our other experiments. It was obvious that it was hard for them to make a decision between the two stimuli.

These results suggest that infants 1–3 months of age do not show a spontaneous preference for a coherent figure over a balanced mixture of large and small blobs. Rather, they seem to be equally attracted by the two textured fields.

8. Experiment 5: Preferences for conflicting, unbalanced stimuli (reversed distributed background)

8.1. Introduction

The results of Experiment 4 show that, when paired with a background stimulus consisting of an identical number of large and small blobs as the target stimulus, but not containing a figure, 1–3 month-old infants do not show a spontaneous preference for either the 'more salient' or the 'less salient' target stimuli. They are equally attracted by a stimulus containing a figure as by a stimulus containing blobs of two different sizes, as long as the content of the target stimulus and the background stimulus are balanced.

Our next question was: would the infants show a different behaviour if background and target stimulus were unbalanced? In other words, would they prefer the 'more salient' or 'less salient' stimulus, if these were paired with background stimuli containing mixtures of blobs of two sizes, but in different amounts? Would they prefer a mixed background pattern, if this pattern contained *more* large blobs than the target stimulus?

To answer this question, we tested 1–3 month-old infants with combinations of stimuli containing either a 'more salient' target stimulus, paired with a background consisting of 16 *small* blobs, randomly distributed amidst large blobs (the number of large blobs in the background was now higher than in the target stimulus), or a 'less salient' stimulus paired with a background consisting of 16 *large* blobs, randomly interspersed amidst small blobs (the number of small blobs was now higher in the background stimulus than in the target stimulus).

8.2. Methods

8.2.1. Stimuli

The stimuli were: (a) the 'more salient' stimulus (4×4 large blobs in a surround of small blobs), paired with a background stimulus consisting of 16 *small* blobs randomly distributed amidst large blobs; and (b) the 'less salient' stimulus (4×4 small blobs surrounded by large blobs), paired with a background stimulus consisting of 16 *large* blobs randomly interspersed amidst small blobs (see Fig. 10).

8.2.2. Apparatus and procedure

Apparatus and procedure were the same as in Experiments 1, 3 and 4.

8.2.3. Subjects

Twelve 1–3 month-old infants participated in this Experiment. The ages of the subjects ranged between 1 month 28 days and 3 months 5 days (mean age 2 months 16 days).

8.3. Results and discussion

The infants showed a consistent *negative* preference for the 'more salient' target stimulus. This "preference" differed statistically highly significantly from chance (38%, $p < 0.01$). Preference for the 'less salient' stimulus did not differ statistically from chance (52%, $p > 0.1$; see right lower panel in Fig. 11).

The most remarkable result of this Experiment is that, if the 'more salient' stimulus is paired with a mixed background containing more large blobs, the preference of the infants is tipped in favor of the background. This

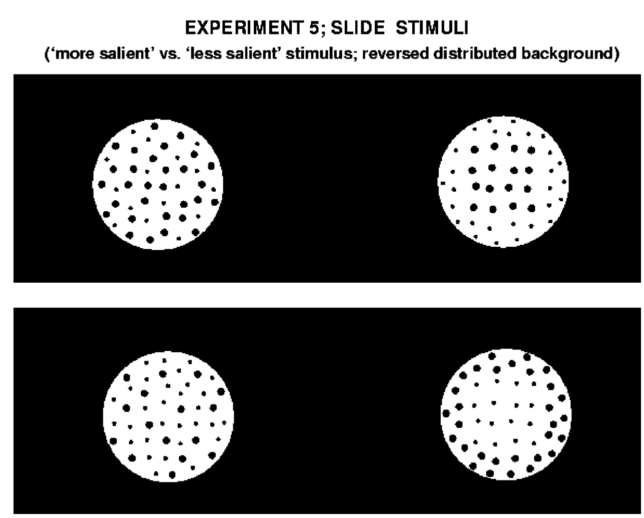

Fig. 10. Stimuli used in Experiment 5. Upper panel: 'more salient' stimulus, paired with a background stimulus containing 16 small blobs, randomly interspersed amidst large blobs. Lower panel: 'less salient' stimulus, paired with a background containing 16 large blobs, randomly interspersed amidst small blobs.

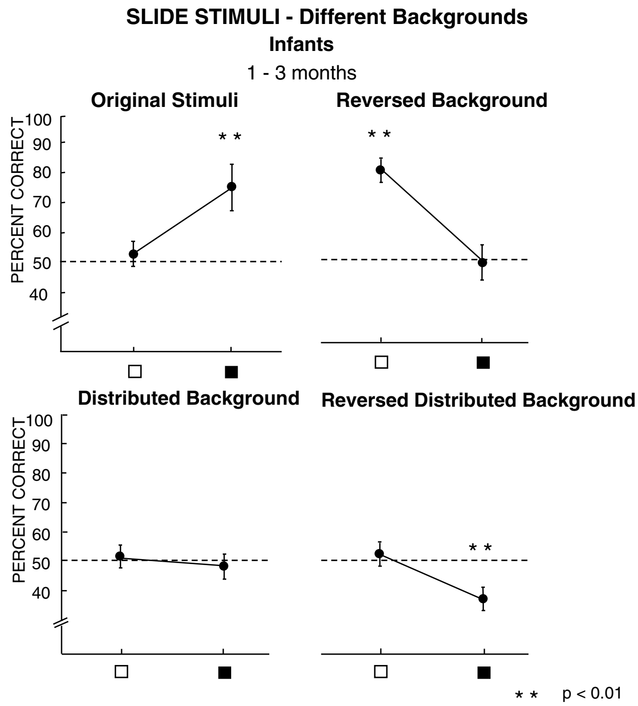

Fig. 11. Percent correct responses of 1–3 month-old infants for the 'more salient' and the 'less salient' target stimulus, in different context situations. Left lower panel: Results of Experiment 4. Percent correct responses for the 'more salient' and the 'less salient' target stimuli, paired with backgrounds containing the same number of randomly distributed small and large blobs. Right lower panel: Results of Experiment 5. Percent correct responses for the 'more salient' and the 'less salient' target stimuli, paired with the reversed backgrounds of Experiment 4. For comparison, the results of Experiments 1 and 3 are replotted in the upper panels (left upper panel: Results replotted from Fig. 4; right upper panel: Results replotted from Fig. 8). Each point is based on the results of twelve infants.

result might suggest that infants prefer patterns containing more large blobs. Nevertheless, this conclusion cannot hold, since in Experiment 3, where the background consisted exclusively of large blobs, the infants did not show a preference for this background. It appears that, for young infants, a higher density of large blobs and a mixture of sizes are necessary in order to render the background more attractive than the target stimulus.

Why, then, did the infants not show a preference for the 'less salient' stimulus, when paired with an unbalanced, mixed background containing less large blobs? This result could be explained by the fact that a weak target stimulus (the 'less salient' stimulus) is now competing with a weak background (a mixed background containing less large blobs than the target stimulus). Obviously, none of the two stimuli is able to command the infants' attention.

8.4. Summary and comments

The results of the Experiments 3, 4 and 5 show that the orienting behaviour of 2-month-old infants is determined not only by the saliency of a target stimulus, but also by the content of its surroundings. Fig. 11 gives a summary of the preferences of the infants for the 'more salient' and the 'less salient' target stimulus, when paired with different backgrounds. The preferences for the 'more salient' stimulus range from a clearly positive preference, when the background consists of small blobs, to a lack of preference, when the background is made either of large blobs only or of a balanced mixture of large and small blobs, to a negative preference, when the background contains blobs of two different sizes and a greater amount of large blobs. The 'less salient' stimulus is only preferred when the background is made exclusively of small blobs.

The negative preference for the 'more salient' stimulus in the last Experiment reminds of the negative preference found by Salapatek (1975) in his matrix experiments and shows that infants' orienting behaviour is indeed guided by perceptual cues different from those responsible for guiding attention in more mature subjects.

9. General discussion

9.1. Evaluation of the results

The aims of the work presented here were: first, to learn whether infants and children show a preference for the 'less salient' as well as the 'more salient' texture-defined object in a visual scene; and second, to investigate the role of context in infants' visual preferences.

In Experiment 1, we found that infants under one year of age show statistically highly significant preferences for the 'more salient' stimulus, thus confirming the results of Sireteanu and Rieth (1992). However, they did not show a preference for the 'less salient' stimulus. Children 3–4 years of age and naïve adults demonstrated highly significant preferences for both the 'more salient' and the 'less salient' stimulus. Experiment 1A confirmed these results with a first-fixation procedure. These results were replicated in Experiment 2, in which the stimuli were presented on a continuous test field. Again, both groups of subjects showed a statistically significant preference for the 'more salient' stimulus. Children aged 3–4 years preferred the 'less salient' target stimulus as well, whereas infants aged 1–3 months did not display a preference for this stimulus.

One possible interpretation of these results is that the infants' attention could have been attracted by both the individual larger blobs (local luminance cue) and the texture border between the larger and smaller blobs (contour cue). In the 'more salient' stimulus, both cues are located on the same side of the experimental set-up and their effects might add up; in the 'less salient' stimulus, they are located on opposite sides, and thus create a conflicting situation.

In Experiment 3, we pitted local luminance cues against contour cues, by pairing the 'more salient' and the 'less salient' stimulus with the reversed backgrounds. In this configuration, infants preferred the 'less salient', but not the 'more salient' target stimulus. Three-to-four year-old children showed a weak, but significant preference for both target stimuli. In Experiment 4, we created a stimulus configuration in which the figure stimuli and the background stimuli contained the same number of small and large blobs. Infants 1–3 months of age seemed to be confused by these configurations; they looked at both stimuli at chance level. The results of Experiments 3 and 4 suggest that the background stimulus plays a crucial role in determining infants' visual preferences. Finally, in Experiment 5, we paired the 'more salient' and the 'less salient' target stimuli with the reversed background stimuli from Experiment 4. Infants 1–3 months of age did not show a preference for the 'less salient' stimulus, when paired with a background stimulus containing 16 large blobs amidst small blobs. But they showed a *reversed preference* for the 'more salient' stimulus, i.e. they looked significantly more often at the mixed background stimulus containing more large blobs than the target stimulus.

9.2. Attentional mechanisms involved in texture segmentation

One possible explanation for the findings of Experiments 1, 1A and 2 might be that infants are more attracted by locally salient stimuli than by the global shape of a group of stimuli. These results are compatible with the notion that the infants' 'spotlight of attention' is *smaller* than that of adult observers: infants are able to process conspicuous local items, but not the contour borders built up by regions consisting of items of different conspicuity. With age, this ability develops, to reach adult-like preferences around 3–4 years of age. This possibility conjoins the suggestion arising from our previous experiments (Sireteanu, 2000; Sireteanu et al., 2003; Sireteanu & Rieth, 1992) that in young infants, local attentional cues dominate over global ones. Convergent indications that infants might be excellent ''analysts'', but poor ''synthesizers'' comes from recent evidence from studies on the perception of faces: indeed, infants are able to identify single face features before they are able to identify faces as a whole (Schwarzer, 2000; Schwarzer, Zauner, & Korell, 2003). Preference for global shape seems to emerge after 1 year of age, indicating the maturation of neural mechanisms involved in the binding of the individual local visual features into coherent figures.

9.3. The role of context in early texture segmentation

The results of this study show that 2-month-old infants display a differential looking behaviour to the same visual stimuli, according to the context in which they are presented. The 'more salient' stimulus elicits either a positive preference when presented alongside a background of small blobs (Experiments 1, 1A and 2), no preference when paired with a background made of large blobs (Experiment 3) or of a balanced mixture of small and large blobs (Experiment 4), and even a *negative* preference, when paired with a stimulus containing a mixture of large and small blobs, with the large blobs prevailing (Experiment 5). The 'less salient' stimulus elicits no preference, if paired with a background consisting of large blobs (Experiments 1, 1A and 2) or a mixture of large and small blobs (Experiments 4 and 5), but it can elicit a positive preference, if paired with a background consisting of small blobs (Experiment 3). In contrast, 3–4 year-old children show a positive preference for the target stimulus in all tested conditions. It thus seems that the context is a crucial factor determining the infants' looking behaviour (for a discussion on the role of competition in early exogenous orienting, see also Dannemiller, 2000).

One possible interpretation for the results of Experiments 4 and 5 might be that infants consistently look at the side of the display containing *more large blobs*, thus not showing a preference for the texture-defined figure. This possibility is ruled out by Experiment 3: If this were true, infants would show a *negative* preference also for the 'most salient' stimulus with a reversed background, since the background contained more large blobs than the target stimulus. But this was not the case. The results of Experiment 5 show that infants display a reverse preference for the 'most salient' stimulus, but only if the background stimulus contains both, more large blobs than the pairing stimulus, and a mixture of large and small blobs.

Taken together, the findings of the present study demonstrate that infants' visual preferences are fundamentally different from adult visual preferences. Further experimental support for this conclusion comes from an independent line of research in our laboratory, which shows that infants' performance in a visual search paradigm is drastically different from that of adult observers. Surprisingly, infants under one year of age do not prefer a broken circle presented amidst an array of closed circles, but show a *negative* preference, orienting clearly towards the background consisting of an array of closed circles. They also do not show a preference for a complete square amidst an array of squares with a missing side, but significantly orient towards the background consisting of an array of aligned open squares. Again, the adult pattern of visual preferences becomes manifest somewhere between the first and the third year of age (Sireteanu, Wagner, & Bachert, 2001; Sireteanu, Rettenbach & Bachert, in preparation).

9.4. Possible neural substrates

The lack of preference of the youngest infants for the 'less salient' target stimulus in the present study reminds of the performance of brain-lesioned monkeys. Indeed, Schiller and colleagues (Schiller, 1993; Schiller & Lee, 1991) reported that lesions in the extrastriate area V4 of adult macaque monkeys affect performance in a visual search task for 'more prominent' or 'less prominent' target stimuli in different ways. The search for an item displaying more of a given quality (larger, darker) than the surrounding items seemed to be relatively unaffected by these lesions, whereas the search for the 'lesser' item was deeply impaired. This result was independent of the stimulus feature (e.g., size, contrast, color saturation, or binocular disparity). The authors concluded that area V4 might be involved in the process of extracting information about 'lesser' stimuli. Similar findings were reported by De Weerd, Peralta, Desimone, and Ungerleider (1999), who investigated macaque monkeys in which the extrastriate area V4 and TEO (an area in the inferior temporal cortex) were lesioned. In monkeys without areas V4 and TEO, visual attention was 'captured' by strong stimuli, regardless of their behavioural significance (but see Merrigan, 2000).

Braun (1994) found that attentive adult observers were equally able to respond to stimuli displaying more or less of a given quality ('more salient' and 'less salient') in a visual search task. If the attention of the subjects was engaged in a concurrent task, performance for the 'less salient' item was severely impaired, while performance for the 'more salient' item was only moderately affected. Braun (1994) suggested that adult observers whose attention was engaged in a concurrent visual task might behave like Schiller's monkeys lacking area V4. Processing of visual stimuli less conspicuous than their surrounding depends on the integrity of extrastriate cortical areas like V4 and TEO. The late development of preference for 'less salient' stimuli in human infants might be indicative of a long-lasting maturation of extrastriate visual areas in the ventral pathway, known to be involved in the deployment of visual attention. These areas belong to the so-called "What", as opposed to the "Where" visual pathway (Goodale & Milner, 1992; Ungerleider & Mishkin, 1982).

Segmentation of a less salient object develops later than segmentation of a more salient object. Missing attentional mechanisms in human infants might be responsible for these results. Thus, infants under one year of age behave like Braun's nonattentive or distracted adults. Both resemble Schiller & Lee's macaque monkeys lacking Area V4. Our findings in human infants might thus reflect a late functional maturation of the human homologue of Area V4.

The differences between the infantile pattern of preferences and the preferences of the more mature subjects suggest that the neural mechanisms directing visual attention under different context situations are still evolving postnatally. At the time being, we can only speculate on the possible neural substrates of these preferences. Salapatek's hypothesis that the infants' preferences are dictated by a visual pattern's amount of contour can be rejected, since in the experiments mentioned above (Sireteanu et al., 2001 and in preparation), the preferred patterns contain either more contour (an array of closed circles) or less contour (an array of aligned broken squares) than the non-preferred target stimuli (an open circle or a closed square). The complexity of contour also cannot explain these findings, since a pattern containing a target is definitely more complex than a regular background, but is not always preferred.

One possible candidate for the early visual preferences might be the spatial frequency content of the visual images. Infants' contrast sensitivity curve is shifted by at least a factor 20 towards lower spatial frequencies when compared to adult contrast sensitivity (Atkinson, Braddick, & Moar, 1977; Banks & Salapatek, 1981). Regular, smooth patterns, like those preferred in the experiments described above (Sireteanu et al., 2001), contain more lower frequencies than patterns containing a deviating element. A background containing small and large blobs, like that in our Experiment 5, contains a larger share of higher spatial frequencies than a pattern made of large blobs only, but it also contains a higher amount of lower spatial frequencies, which might have been decisive in commanding the infants' attention.

There are several other neural events taking place during the developmental period covered in the experiments reported here. Most pertinent to the subject of this study are the connections supporting contextual modulation and figure-ground segmentation. In adult cats, these functions were suggested to be realized either by the tangential intracortical connections in area 17 (Das & Gilbert, 1999), or by the cortical top-down projections from the extrastriate to the primary visual areas (Hupé et al., 1998; Lamme & Roelfsema, 2000). Both systems of connections develop postnatally. In humans, feed-back projections from the secondary to the primary visual cortex are later to develop than the feed-forward projections connecting the same areas (Burkhalter et al., 1993). Further investigations are needed before a final decision concerning the events responsible for explaining the intriguing findings on infants' early visual preferences can be made.

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